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The association of Fire Occurrence and Past Western Spruce Budworm Activity in Dry Douglas-fir Habitat types of Western Montana

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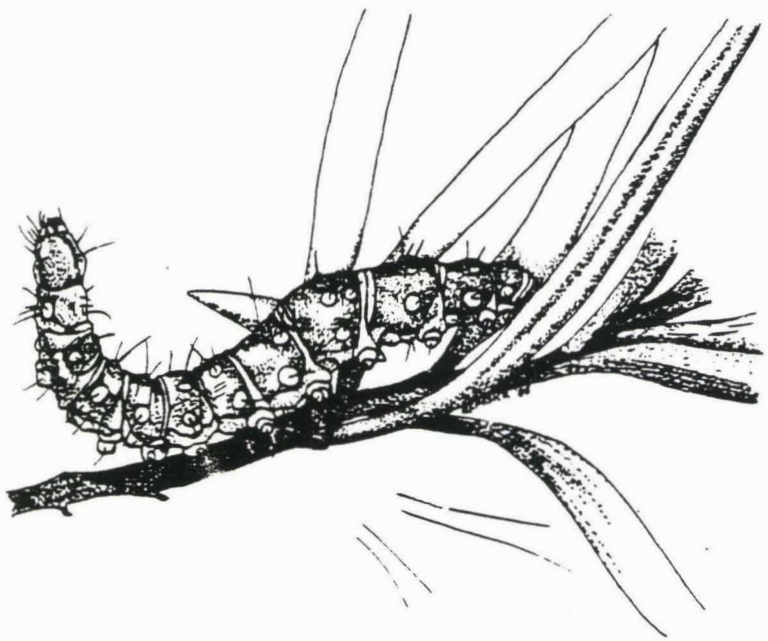

Leslie Anderson
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The Association of Fire Occurrence and Past Western Spruce Budworm Activity In Dry Douglas-fir Habitat Types of Western Montana

by

Leslie L. Anderson

B.S., University of California, Berkeley, 1982

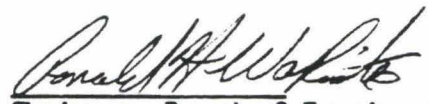
Presented in Partial Fulfillment of the Requirements for the Degree of

Master of Science

UNIVERSITY OF MONTANA

1985

Approved by:



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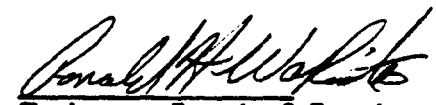

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The Association of Fire Occurrence and Past Western Spruce Budworm Activity in Dry Douglas-fir Habitat Types of Western Montana (66 pp.)

Director: Ronald H. Wakimoto R.H.W.

The western spruce budworm (Choristoneura occidentalis) is a widely distributed defoliator of forest trees in western North America, causing growth loss, top kill, and mortality. Current literature suggests that fire suppression has predisposed forest stands to budworm infestation by altering stand structure and species composition. The objective of this study was to determine the association of fire occurrence and western spruce budworm activity. Frequency, duration, and severity of budworm outbreak were the dependent variables. Mean fire interval and fire frequency were the independent variables. Budworm activity and fire occurrence were estimated and compared over two time periods: the pre-fire suppression time period, prior to 1910, and the fire suppression time period, 1911-1983. Twenty stands were sampled in western Montana. Significant increases of mean fire interval were apparent for the fire suppression period. Significant increases of duration, severity, and weighted frequency of apparent budworm outbreak over all the stands sampled were also apparent. No significant correlations were found between values of outbreak frequency, duration, or severity, and the values of mean fire interval for individual stands. However, the weighted frequency of apparent budworm infestation by decade was significantly correlated to fire frequency by decade. No increases were apparent for the frequency of budworm activity, nor for any of the budworm activity variables for individual stands.

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INTRODUCTION

The western spruce budworm (Choristoneura occidentalis), (WSBW), is a widely distributed insect in the forests of western North America, that causes growth loss and in some cases mortality in host trees. Between 1926 and 1972 three major budworm outbreaks occurred in western Montana (Johnson and Denton 1975). This period of time is synchronous with the implementation of an effective fire suppression program that changed the role of fire as an ecologic influence on national forest lands. Researchers have suggested that reduced fire occurrence has allowed some forest stands to become more susceptible to WSBW infestation by changing forest successional patterns and altering stand structure and species composition (Arno 1976, Fellin 1980, McCune 1982, Wright 1973).

In the absence of fire, stand conditions can result that may affect the extent and persistence of WSBW outbreak (Carlson, Fellin, and Schmidt 1982). Many seral, fire-maintained communities of ponderosa pine (Pinus ponderosa), western larch (Larix occidentalis), and Douglas-fir (Pseudotsuga menziesii var. glauca) in Douglas-fir climax forest types (Pfister et al. 1977) have gradually been replaced by multi-storied stands dominated by shade tolerant species (Arno 1980, Dickman 1978, Schmidt 1981). These current stand conditions are favorable for the WSBW (Fauss and Pierce 1969). Therefore, the present study was concieved to investigate the nature of the association between

fire occurrence and WSBW activity. Knowledge of such associations might be useful for developing stand management alternatives.

Objectives

The objectives of this study are:

1. To determine whether values of WSBW outbreak frequency, duration, and severity were significantly larger in the time period of fire suppression than in the period prior to fire suppression.
2. To test the supposition that the mean fire intervals in the time period of fire suppression were significantly longer than those in the period prior to fire suppression. Other fire history studies already confirm this supposition (Stokes and Dieterich, 1980).
3. To determine whether fire occurrence and the variables representing WSBW activity are correlated.

LITERATURE REVIEW

The western spruce budworm, is one of the most widely distributed forest insects in western North America, (Johnson and Denton 1975). Effects of the budworm on host trees include the reduction of annual growth and seed production, top kill, and mortality of many coniferous trees (USDA 1976). In most host tree species, the budworm acts as a defoliator, its larvae feeding on needles, new buds and shoots (Fellin,

et al. 1983). The degree of defoliation depends on:

1. the duration of outbreak (typically one to thirty years (Fellin, et al. 1983)), 2. the density of budworm population, 3. the relative susceptibility of individual host trees to larval feeding (due to genetic differences (McDonald 1979), and to differences in tree size and position), and 4. the stand composition (Johnson and Denton 1975).

The most common WSBW host tree species are Douglas-fir, grand fir (Abies grandis), subalpine fir (Abies lasiocarpa), Engelmann spruce (Picea engelmannii), and western larch. The budworm often consume or destroy much of the new foliage on their host trees (Fellin, et al. 1983). Most trees recover from the defoliation unless there is a sustained attack with many trees almost entirely defoliated (Whiteside and Carolin 1961). However, the trees that do recover often succumb later to other insects and decay.

Throughout most of its range the WSBW completes its egg to adult cycle within twelve months. Each female lays approximately 150 eggs in late July or early August; these are hatched in approximately ten days. Usually there are six larval instars. The first instar larvae do not feed but seek hiding places among lichens or bark. Here they spin webs which become their hibernacula where they remain through the winter as instar II. In early May to late June the larvae move to foliage where they begin to mine old needles. When the new buds swell the larvae bore

into these expanding buds. As the new shoots unfurl the larvae spin webs between the needles and tips, where they feed on new foliage. After thirty to forty days of feeding, the larvae are fully grown and pupation occurs. The adult moths emerge after about ten days pupation (Fellin and Dewey 1982).

Of the many factors that affect WSBW populations, weather and stand properties are the most important (Williams et al. 1971). Hot, dry weather favors larval feeding, development, and survival in all instars over cool cloudy weather, (Wellington 1949). A study in the USDA Forest Service's Northern Region indicated that defoliation varied directly with the mean maximum temperature and inversely with the frequency of measurable precipitation during May June, and July of the previous year (Hard, et al. 1980).

Stand properties that increase the solar radiation to tree crowns and decrease relative humidity are favorable for WSBW. Stands with open grown trees have the highest insect survival rates of fourth through sixth instar larvae up to the point where food shortages begin. Dense stands are more favorable to dispersing first and second instar larvae as these larvae are more likely to land on a second host tree in dense stands than open stands (Williams, et al. (1971). The dispersal periods of these larvae immediately after hatching or emergence from their hibernacula are responsible for the highest mortality of budworm larvae (Miller 1958).

The history of the closely related eastern spruce budworm (Choristoneura fumiferana) was retraced by Blais (1981), through radial growth studies on old white spruce (Picea glauca) and black spruce (Picea mariana) in the Ottawa River Valley of Quebec. This study revealed that three outbreaks occurred in the twentieth century, whereas there was no evidence of an outbreak during the nineteenth century. A reduction in radial growth starting in 1783 appeared to be caused by budworm outbreak, but evidence was insufficient to confirm this. McCune (1982), examined radial growth on several host tree species of the WSBW in the Bitterroot Range of Montana, and surmised that the intensity of the most recent outbreak was unprecedented in the last one hundred years. He speculated that fire suppression has aggravated the budworm problem.

Successional changes in ponderosa pine forests in the absence of fire were illustrated by Gruell et al.(1982), Arno (1976), and Dickman (1978). Prior to 1900 frequent fires killed Douglas-fir regeneration, maintained open stands of mature ponderosa pine and prevented the establishment of Douglas-fir understories. In recent years, in the absence of fire, Douglas-fir has become the understory dominant because of its greater shade tolerance.

The increased abundance of shade-tolerant budworm-susceptible species such as Douglas-fir and grand fir that result from fire exclusion and partial cutting practices results in conditions that are

favorable for WSBW. The budworm's food supply is increased, and the dense stands experience high defoliation and mortality (Fellin et al. 1983). Although budworm larvae have higher survival rates in open grown trees, such trees are usually thriftier and can survive and recover more quickly since they have more buds and are under less intense root competition for water. In the Bitterroot National Forest, the highest tree mortality occurred in small, dense, heavily defoliated stands of Douglas-fir sawtimber on upper portions of north facing slopes. Few of the Douglas-fir that were killed by defoliation grew near streams or in the open on south to west facing slopes (Williams et al. 1971).

Fauss and Pierce (1969) studied the relationship of stand and site characteristics to the amount of defoliation caused by a WSBW outbreak in the Blackfoot River drainage of western Montana. They concluded that more intense defoliation was associated with drier sites, dense stocking, and high percentages of Douglas-fir relative to ponderosa pine. Other research has supported the contention that dense stands of host trees are highly susceptible to WSBW outbreak (Carlson, Fellin, and Schmidt 1983).

The lack of fire may also adversely affect budworm predators and parasites, such as predaceous ant species. Two predaceous ant species, Formica obscuripes and Formica drinivetris prefer to build their nests on warm sunny slopes or meadows. Ant foraging activity also increases with increasing temperatures as the sun warms the nests. More open

stand conditions associated with ten to thirty year fire intervals seem to favor habitats more optimal for these two ant species (Bain 1972).

METHODS

Study Areas

Twenty stands were sampled in western Montana, on the Bitterroot, Lolo, and Kootenai National Forests, during the Fall of 1983 and Spring of 1984, (see Table 1 and Fig. 1). The stands were all of dry Douglas-fir habitat types including Psme/Phma, Psme/Caru, Psme/Syal, and Psme/Fesc (Pfister et al. 1977). All the stands contained old growth Douglas-fir and ponderosa pine and had little or no evidence of ever having been logged. Sixteen of the twenty stands were selected because they also had previously established fire histories, (Arno 1976; Barrett 1981). This was done to take advantage of available information in order to invest more effort on the study objectives.

The size of sampling units used to determine past budworm history varied between sample locations because I used a circular sampling pattern with successively wider circles to select trees, until the required number of sample trees had been located. In stands with previously established fire histories, the individual sample trees used in these studies were located and the budworm sample trees were selected in the same vicinity. The total size of the sampling units averaged between ten and thirty acres. The data were analyzed at the stand level

TABLE 1: SAMPLING UNIT DESCRIPTIONS

	SAMPLING UNIT	LOCATION	*HABITAT TYPE	ELEVATION
1	Lolo Cr.	T12N, R23W, NW26	PSME/PHMA	4000-4400'
2	Hobo Gu.	T11N, R18W, SE13	PSME/PHMA	4000-5000'
3	Rock Cr.	T14N, R22W, SE25	PSME/FESC	4400-4700'
4	Horner	T14N, R21W, NW22	PSME/SYAL	3800'
5	Grizzly Cr.	T10N, R16W, NE3	PSME/PHMA	4400-4800
6	Hay Cr.	T14N, R24W, NE9/NW10	PSME/PHMA	4800-5000'
7	Onehorse Cr.	T11N, R20W, S33	PSME/PHMA	4100-4500'
8	Railroad Cr.	T5N, R18W, NE2	PSME/PHMA	5000-5200'
9	Goat Mtn.	T5N, R21W, SW9	PSME/SYAL	4500-5500'
10	Cutoff Gu.	T7N, R18W, NE6	PSME/PHMA	5200-5800'
11	McCalla Cr.	T9N, R21W, SW36	PSME/CARU	5100-5600'
12	Hog Trough Cr.	T5N, R18W, NW3	PSME/SYAL	5100-6000'
13	Indian Trees	T1S, R19W, SW9/SE8	PSME/SYAL	5400-5800'
14	Tolan Cr.	T1N, R19W, SW13	PSME/PHMA	5200-5500'
15	School Pt.	T1N, R22W, NE24	PSME/CARU	5100-5500'
16	Hugnes Cr.	T2S, R22W, NE24/NW35	PSME/SYAL	5200-6000'
17	Two Bear Cr.	T4N, R19W, SE4/SW3	PSME/SYAL	6700-6800'
18	Doak Cr.	T31N, R30W, NE18	PSME/SYAL	3400-3700'
19	Five Mile Cr.	T32N, R28W, NE17	PSME/SYAL	2700-3100'
20	Rainy Cr.	T31N, R30W, SW3	PSME/SYAL	4000-4100'

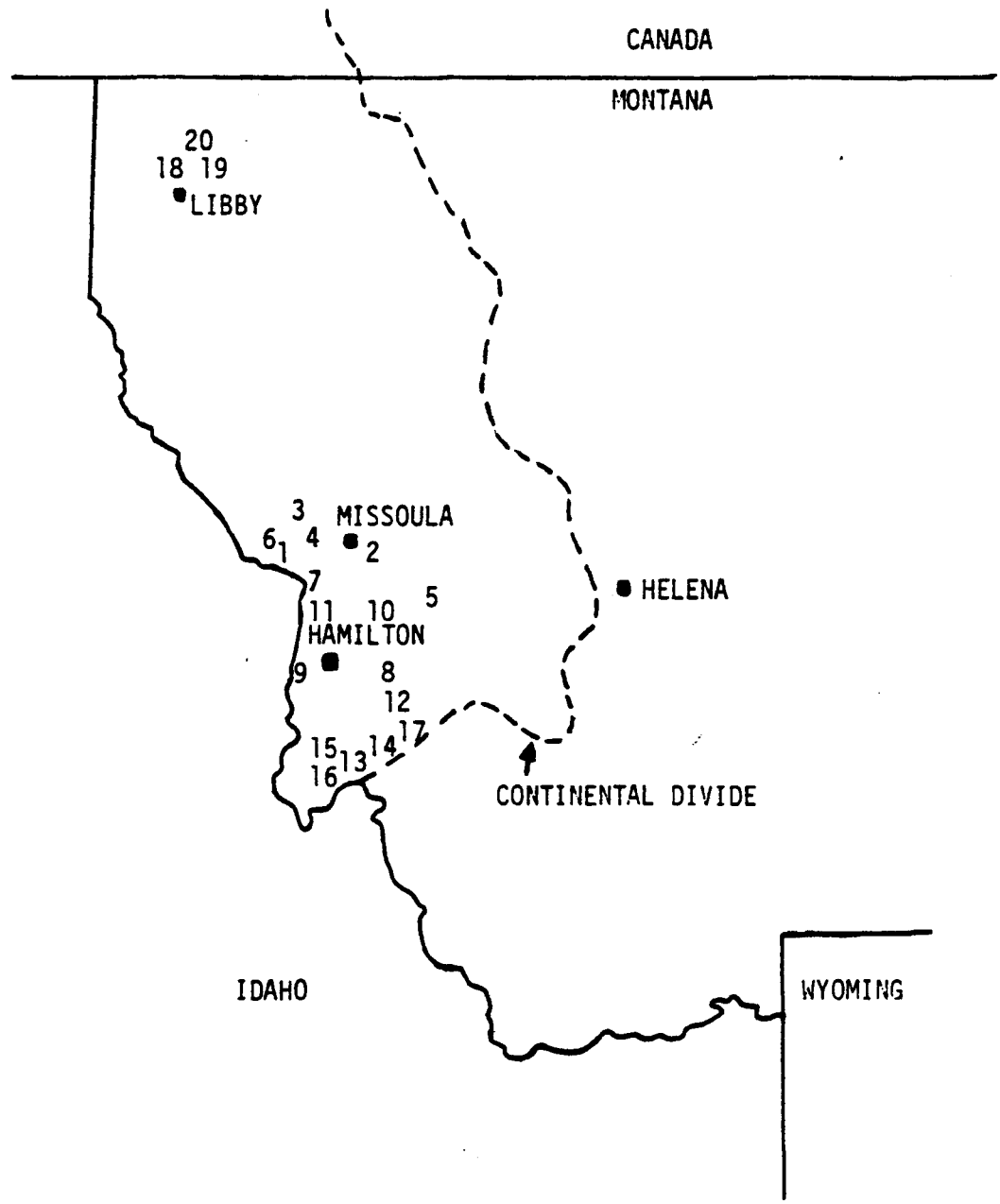
(CONTINUED ON NEXT PAGE)

*Pfister et al., 1977.

TABLE 1: (CONTINUED)

SAMPLING UNIT	% SLOPE	ASPECT (IN DEGREES)	SLOPE POSITION	SHAPE
1	40-65%	140-200	LOWER 1/3	CONCAVE
2	45-60%	220-250	UPPER 1/3 & RIDGETOP	CONVEX
3	40-65%	180-310	LOWER & MID 1/3	CONVEX
4	5-20%	30-80	FLAT BENCH, MID 1/3 OF SPUR RIDE	CONVEX
5	50-70%	120-170	LOWER 1/3	CONCAVE
6	35-55%	230-270	UPPER 1/3	CONCAVE
7	25-55%	60-150	MID 1/3	CONVEX
8	65-75%	150-180	LOWER 1/3	CONVEX
9	30-45,75%	50-150	MID 1/3 OF SPUR RIDGE AND STEEP SLOPE OFF RIDGE	CONVEX
10	60-70%	120-160	MID 1/3 AND TOP OF SPUR RIDGE	CONVEX
11	55-80%	130-200	MID 1/3 TO TOP OF SPUR RIDGE	CONCAVE
12	65-85%	140-180	LOWER 1/3 AND TOP OF SPUR RIDGE	CONVEX
13	60-65%	165-190	LOWER 1/3 TO TOP OF SPUR RIDGE	CONVEX
14	20-60%	60-110	UPPER 1/3 & RIDGETOP	CONCAVE
15	35-55%	60-110, 225-240	TOP OF SOUTH FACING SPUR RIDGE	CONVEX
16	40-50%	230-280	LOWER 1/3	CONCAVE
17	10-45%	80-155, 240-260	RIDGETOP	CONVEX
18	35-55%	265-270	UPPER 1/3	CONVEX
19	10-40%	190-170	LOWER 1/3	CONVEX
20	15-35%	80-180	MID 1/3	CONCAVE

FIG. 1



LOCATIONS OF SPRUCE BUDWORM / FIRE HISTORY SAMPLE AREAS

of resolution. Although this may have "hidden" some of the variation in the dependent variable because individual tree values were averaged to obtain stand values, it was necessary in order to have the same resolution for both the independent and dependent variables.

The dependent variable, (WSBW activity), and the independent variable, (fire occurrence), were compared over two time periods of each stand: 1) the pre-fire suppression period, from 1814 to 1910; and 2) the fire suppression period, from 1911 to 1983. The mean fire intervals prior to 1910 were calculated based upon records extending from 1780 to 1910. This longer fire period was used to obtain a better representation of mean fire intervals. The year 1780 was selected as the starting point because prior to this time fire records become incomplete because of a diminishing supply of sufficiently old fire-recording trees. Values for the dependent and independent variables were calculated separately for each time period within each stand.

The year 1910 was selected as the end of the pre-fire suppression period because it is a customary date used in fire history studies (Barrett, 1981; Arno and Peterson, 1983; Davis, 1980). The Great Idaho Fire of 1910 resulted in a new sense of the necessity for fire suppression in Montana. The Northern Montana Forestry Association was formed in September, 1910, to protect 2.5 million acres in western Montana. Although the effects of fire suppression may not have been

apparent for several years after its initiation, 1910 was still considered an appropriate date since other forces, such as the diminishing influence of fires ignited by Indians in the late 1800's (Barrett 1981) had begun to decrease the number of fires prior to 1910.

Determination of Fire Occurrence

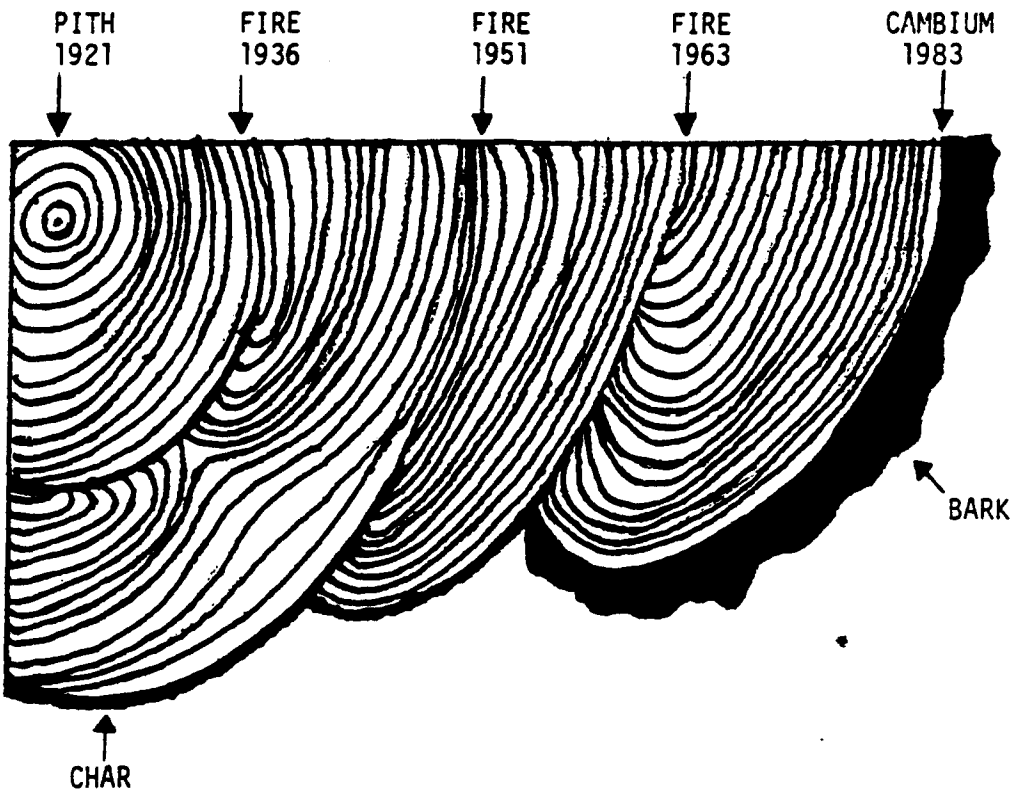
The independent factor, fire occurrence, was quantified by time period for each stand using mean fire interval (MFI) which is the arithmetic average of the number of years between successive fires determined in a designated area during a designated time (Romme, 1980). A second variable used to quantify fire occurrence was the number of fires in all stands sampled by decade. Historic fire occurrence was determined using methods developed by Arno and Sneck (1977). Sampling varied from described methods in that a detailed inspection of all old trees in the stand vicinity was used to locate fire-scarred trees rather than examining only those trees on transects. The transect method is more appropriate for larger study areas.

Three to five old, mature trees, distributed throughout the stand and exhibiting the greatest number of intact fire scars were subjectively selected as sample trees. It was necessary that the fires scars on the sample trees be in reasonably good condition, (not largely burned off or excessively decayed), so that the year of fire occurrence could be determined. Sample tree information, including species, d.b.h., maximum height of "catface", the number of externally visable

scars, the actual number of scars revealed on the cross section, elevation, and aspect was recorded. The fire scar sequence on each tree was cross sectioned with a chainsaw. This often resulted in severing ten to fifteen percent of the basal area of the stem which apparently does not greatly damage most ponderosa pines (Arno and Sneck 1977). The cross sections were then taken to the lab, air dried, sanded, and analyzed.

With the aid of a binocular microscope, the date of each fire scar was determined by counting the annual rings from the bark to each scar. A schematic example of one of these cross sections is shown in Fig. 2. Fire scar records from individual trees were combined to form a "master fire chronology" for each stand (Arno and Sneck 1977). This provides a more accurate estimate of the sequence of fire years. When the fire years from the individual trees did not match up to create a plausible master fire chronology, the site was revisited and more samples were collected. This was done to ensure that a relatively complete and accurate record had been obtained. In study areas having previously determined fire histories, the fire histories were compiled from those individual sample trees that were located within the small sample stand. The mean fire intervals for the pre-fire suppression and fire suppression time periods were then calculated from the master fire chronology. Dendrochronologic cross-dating was not used to establish greater precision of actual fire dates, since the greatly increased expense of this procedure would have been prohibitive and the added

FIG. 2: DETERMINATION OF FIRE YEARS FROM FIRE SCAR SAMPLE



precision provided seemed unnecessary for this study (Madany et al. 1983; McBride 1983).

A method described in Arno and Peterson, (1983), was used to lengthen the usable portion of the fire record, specifically to allow the calculation of MFI for time periods in which zero or only one fire occurred. In the pre-fire suppression time period (1780-1910), an interval, from the last fire in the period until 1910, was added to the record, if this additional interval would result in the lengthening of the mean fire interval. The rationale for this is that although we do not know what the length of this final fire interval would have been had fire suppression not intervened in 1910, we know that the interval would have been at least as long as the period from the last fire to 1910 and that when this partial interval was longer than the mean interval, its addition should improve the estimate of the true mean (Arno and Peterson 1983).

Similarly, in the fire suppression time period, 1911-1983, intervals were added between 1911 and the first fire, as well as between the last fire and 1983, if their inclusion lengthened the MFI. This method was varied slightly for stands in which only one fire occurred during the fire suppression time period. Instead of calculating two intervals for the time period, one on either side of the date of the fire, the entire period was considered a single interval, consisting of the two partial intervals. Thus, the MFI in these cases equaled 72

years.

Determination of Past Budworm Activity

Past western spruce budworm activity was assessed using techniques of radial increment analysis of cores from paired WSBW host/nonhost tree species as described in Carlson and McCaughey (1982). Three variables were used to quantify budworm outbreak. The variables were: frequency of outbreak, (the number of outbreaks during a specified period of time); duration of outbreak, (the number of years between the beginning and end of an outbreak), and severity of outbreak, quantified using a severity index. A fourth variable, termed "weighted frequency", was calculated by summing the total years of budworm outbreak in all stands by decade. For example, in the decade 1841-1850, stand 14 had seven years of outbreak and stands 4 and 15 each had eight years. Thus, the weighted frequency of the decade ending in 1850 was 23 years.

These four variables collectively provide much information for interpreting the extent of past WSBW activity. Aerial survey records of WSBW damage were considered inadequate for use in this study as they extend back only to the 1930's, lack resolution at the stand level, and do not provide a means to measure outbreak severity.

Five tree pairs were selected in each stand. Each pair included a WSBW host tree, (a Douglas-fir), and a nonhost tree (a ponderosa pine). Each tree sampled was a dominant or codominant, live, at least 130 years

old, and at least twenty meters from cutting boundaries, stumps or roads. Where possible the two trees of a pair were chosen so that their diameters were similar. Sample fire scarred trees were often rotten or pitchy toward the pith so they often could not be used in the pairs.

Sample tree information, including species, d.b.h., slope, aspect, and crown (dominance) class was recorded. Two increment cores were extracted from opposite sides of each tree at breast height parallel to the topographic contour. The cores were stored in labeled thermatically sealed, plastic straws. The annual increments were then measured and recorded in the laboratory using an Addo-X machine, a calibrated sliding stage with an attached counter that is used with a binocular microscope. The increments were measured to within .1 millimeter, the precision of the Addo-X.

A cumulative growth function (CGF) was developed by species for each stand in order to graphically compare growth between species and accentuate deviation from normal growth in the host species (Carlson and McCaughey 1982). Cumulative growth function is defined as:

$$G_{cum} = \sum_{i}^{n} g_i^2$$

where g_i is the mean incremental growth for year i, and i and n are the first and last years of the time period of interest. The years bounding the pre-fire suppression time period were 1814 and 1910, while those bounding the fire suppression time period were 1911 and 1983. A computer program, provided by the Forest Service Intermountain Forest

and Range Experiment Station was used to compute and plot CGF curves.

The CGF curves were examined for evidence of WSBW outbreak. Variation of radial growth caused by the effects of annual climatic fluctuations, site, and stand density, was controlled by comparing the radial growth of the WSBW host tree with that of the nonhost tree. Visually obvious negative departures of the Douglas-fir curve relative to the ponderosa pine curve indicated radial growth loss due to WSBW outbreak. A minimum negative departure of six years was chosen to indicate a budworm outbreak. This minimum duration excluded very few potential outbreaks, but was selected because it is too speculative to attribute shorter periods of growth loss to budworm activity.

For a graphical description of the methods of determining the values of apparent WSBW outbreak frequency, duration, and severity, see Fig. 3. Frequency of apparent outbreak was determined by counting the number of apparent outbreaks in each stand within each time period and dividing by the total number of years in the period, (96 years for the pre-fire suppression time period, and 73 years for the fire suppression time period). These values were then transformed to arcsin frequency, a transformation appropriate to percentages and proportions (Sokal and Rohlf 1981). Duration of outbreak was determined by counting the number of years between the beginning and end of the growth suppression periods. The severity index of each outbreak was computed using the following formula (Carlson and McCaughey 1982):

Fig. 3: Description of Methods for Determining Values of WSBW Outbreak Variables
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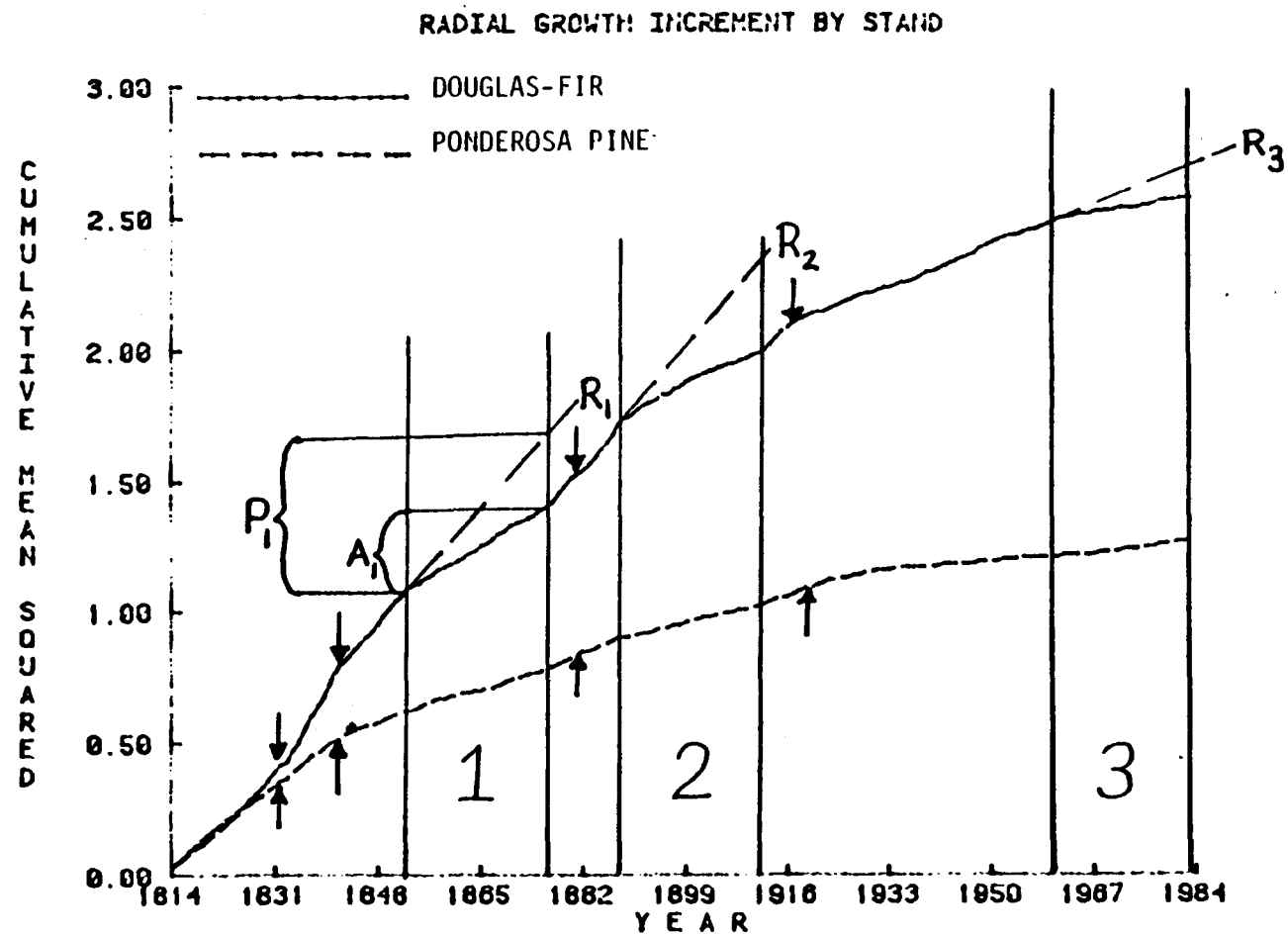


FIG. 3: DESCRIPTION OF METHODS FOR DETERMINING VALUES OF WSBW OUTBREAK VARIABLES

Numerals (1,2,3)=periods of budworm outbreak, where there is a decrease in the growth of Douglas-fir without a synchronous decarease in the growth of ponderosa pine.

Arrows (⟶)=synchronous growth depressions in Douglas-fir and ponderosa pine. Because the growth depressions are synchronous they are not considered budworm outbreaks.

R_i =regression of Douglas-fir CGF against time from the last visually noticeable change in Douglas-fir growth to the end of the growth depression (WSBW outbreak) period. R indicates the potential growth of the Douglas-fir during the outbreak period.

P_i =the potential growth of Douglas-fir in the stand durin the outbreak period as measured by cumulative mean squared increment.

A_i =the actual growth fo the Douglas-fir in the stand during the outbreak period, as measured by cumulative mean squared increment.

OUTBREAK FREQUENCY: determined by counting the number of outbreaks in a time period and dividing by the number of years in the time period. The outbreak frequency in the pre-fire suppression time period, 1814-1910, for this example=

2 outbreaks/96 years = .021 outbreaks/year

These values were then transformed to $\arcsin\sqrt{\text{frequency}}$ for statistical calculations.

OUTBREAK DURATION: determined by counting the number of years between the beginning and end of each period of growth depression (outbreak period). Outbreak 1 in this example began in 1853 and ended in 1876. Thus the duration of this outbreak was twenty three years.

(Continued on next page)

FIG 3 (Cont.)

OUTBREAK SEVERITY: determined using the following equation:

$$\text{Severity Index} = 1 - A/P$$

where A equals the actual growth of the Douglas-fir during the outbreak and P equals the potential growth of the Douglas-fir during the outbreak. The actual growth (A), during outbreak 1 in the example=

CGF at end of outbreak (1876) - CGF at beginning of outbreak (1853)

$$= 1.40 - 1.09 = .31$$

The potential growth (P), during outbreak 1 in the example=

Potential CGF at end of outbreak (1876) -
CGF at beginning of outbreak (1853)

$$= 1.71 - 1.09 = .62$$

The severity index of outbreak 1 in the example =

$$1 - A/P = 1 - (.31/.62)$$
$$= .50$$

Severity Index = 1 - (A/P)

where A/P is the ratio of actual CGF during the outbreak period to potential CGF during the outbreak period. Potential CGF was determined by developing a regression of CGF against time between the last visually noticeable change in the growth rate until the end of the outbreak. The severity index lies between 0 and 1, with 1 indicating the greatest impact. The mean severity index of outbreaks by time period was calculated for each stand by summing the values of actual growth (A),and summing the values of potential growth (P) for all the outbreaks in the stand in the time period, and using these values in the severity index equation.

Insect damage survey records and insecticide spray program records were reviewed and interpreted relative to the sample data.

Stand Vegetation History

On every fourth study area, historic stand species composition and structure was reconstructed. A 375 m^2 plot was centered at each of thre of the stands' fire scar sample trees. The trees in the plot were recorded by species by 5 cm. size classes. Three trees in each size class were increment bored and the rings counted with a 10X hand lens to determine age. Smaller trees were bored near the ground to obtain more accurate ages. If the ages of the trees in any one size class differed by more than ten years, more trees were bored until a more precise age class could be determined. These cores were stored in labeled straws

and returned to the laboratory for more accurate aging. Live crown ratios, (the ratio of the height of the live crown to the total height of the tree), were recorded for each tree bored. The basal area per acre of the sample plot and the presence of tiers or stories in the vegetation were also recorded.

Analysis

Paired t-tests were run on the stand values of mean fire interval (MFI), outbreak frequency, average outbreak duration, and average outbreak severity to compare the stand means between the pre and post 1910 time periods. The null hypothesis tested for each variable was:

> The values of variables representing WSBW activity and fire occurrence for individual stands are not greater in the fire suppression time period than in the pre-fire suppression time period.

Grouped t-tests were run on the actual values of outbreak duration and severity for all apparent outbreaks detected in all twenty stands sampled, and for the weighted frequency by decade to compare means of each between the two time periods. The hypothesis tested for each variable was:

> The values of variables representing WSBW activity over all stands sampled are not greater in the fire suppression time period than in the pre-fire suppression time period.

Simple linear correlation coefficients between the stand mean fire interval and the stand WSBW activity variables were calculated for each time period. Fisher's exact z test was used to test the significance of the correlations. Simple linear correlation coefficients between the weighted frequency by decade and the number of fires by decade were also calculated and Fisher's exact z test was used to test the significance of the correlation.

All t-tests and z tests were assessed for significance at the 5% level.

RESULTS

Fire History

Fires (actually "fire years") were detected in each of the twenty stands sampled, with a range of four to twenty one fires per stand. Two hundred thirty three fires occurred over all the stands between 1780 and 1983. Two hundred two fires occurred between 1780 and 1910 in the pre-fire suppression time period. Thirty one fires occurred between 1911 and 1983 in the fire suppression time period. For individual stand fire histories, see Appendix 1.

Stand mean fire interval (MFI) by time period ranged from 6.6 to 72 years for The twenty stands and two time periods. As expected a paired one-tailed t-test on stand MFI's showed that the MFI's associated with the fire suppression period were significantly longer than those

associated with the pre-fire suppression period (Table 2).

Western Spruce Budworm History

A total of twenty seven apparent budworm outbreaks were detected in fifteen of the twenty stands sampled. The remaining five stands showed no historical budworm activity. The number of apparent outbreaks in the period 1814-1983 ranged from zero to four outbreaks per stand. Sixteen of the apparent outbreaks began between 1814 and 1910, during the pre-fire suppression time period. The remaining eleven apparent outbreaks began between 1910 and 1983 in the fire suppression time period. The apparent outbreak frequency, average duration, and average severity, and MFI by time period are listed for each stand in Appendix 2.

The occurrence of outbreaks and fires by stand is illustrated in Fig. 4. There appears to be a trend of increased budworm activity in the fire suppression time period. However, the differences by stand in the budworm activity variables between the two time periods were not significant statistically. Significant increases in the values of outbreak duration and severity, and weighted frequency by decade were found when these values were tested as groups by time period.

TABLE 2: RESULTS OF WITHIN STAND PAIRED T-TESTS OF WSBW OUTBREAK VARIABLES

Variable	Cases	Mean		Standard Error		T Value	Significance
		Pre-1910	Post-1910	Pre-1910	Post-1910		
MFI (Years)	20	15.1	49.3	1.35	5.83	-6.11	*
Frequency (Transformed)	20	.073	.058	.013	.015	0.89	-
Duration (Years) (Ave.)	20	7.9	12.0	1.70	3.81	-1.00	-
Severity (Index) (Ave.)	20	.315	.307	.061	.078	.99	-

*SIGNIFICANT AT = 5% LEVEL

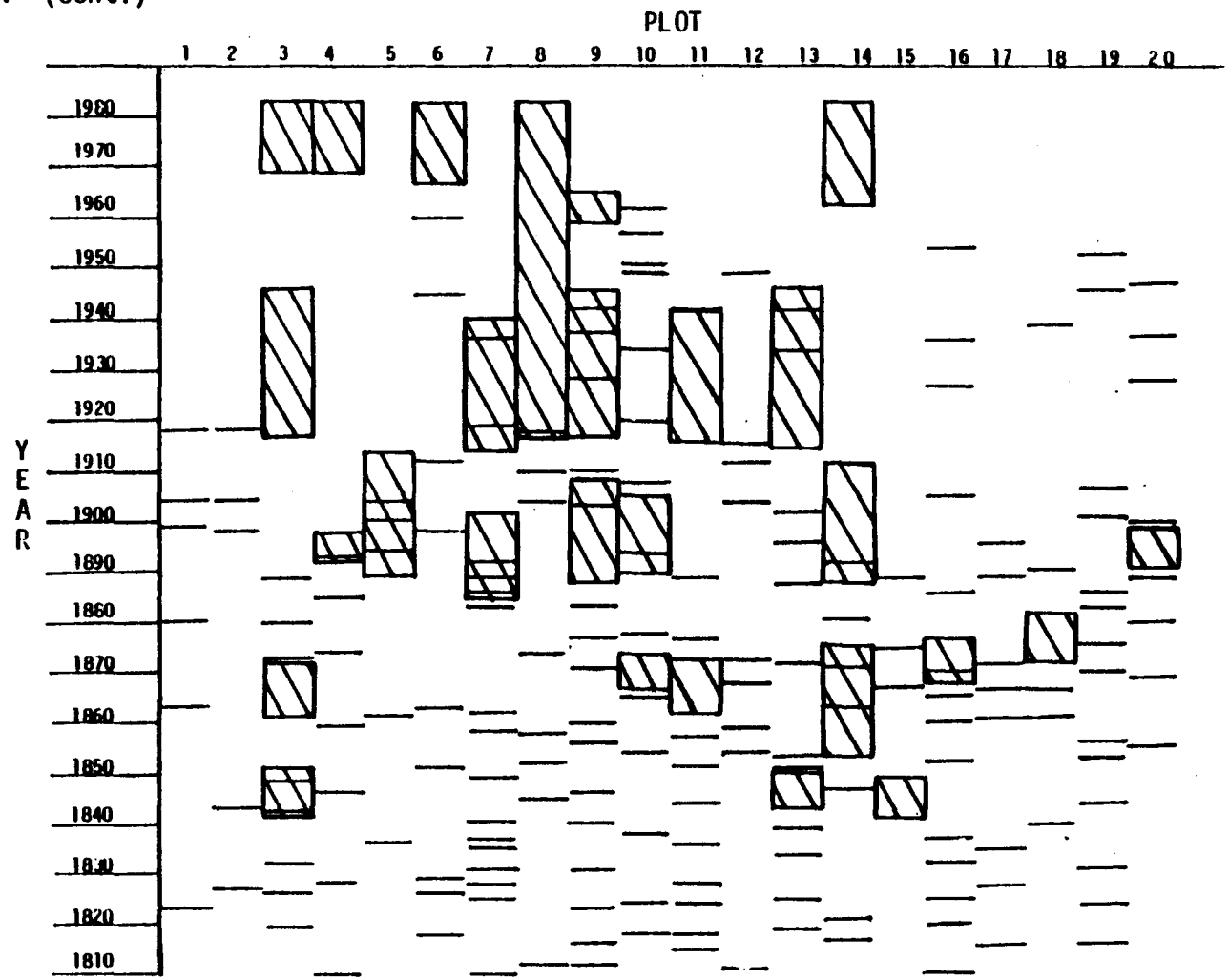
FIG. 4: CHART OF PERIODS OF APPARENT BUDWORM OUTBREAK AND YEARS OF FIRE OCCURRENCE

KEY:

= PERIOD OF APPARENT BUDWORM OUTBREAK

——— = FIRE YEAR

Fig. 4: (cont.)


PLOT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
YEAR
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1860
1870
1860
1850
1840
1820
1810

Outbreak Frequency

A paired one-tailed t-test of the transformed values of outbreak frequency indicated no significant increase in the frequency of budworm outbreak in the fire suppression time period compared to the pre-fire suppression time period (Table 2). Simple linear correlation coefficients between outbreak frequency and MFI were calculated for each time period and a one sample two-tailed z-test showed no significant correlations at the =.05 level, (Table 3).

Outbreak Duration

The actual duration of outbreaks ranged from the minimum accepted value of six years to a maximum of sixty six years. The average duration of outbreaks by stand and time period ranged from zero, for time periods with no budworm activity, to sixty six years. A paired t-test of the values of average duration indicated no significant increase in outbreak duration in the fire suppression time period, (Table 2). Simple linear correlation coefficients between average duration by stand and stand MFI were calculated for each time period, and a one sample two tailed z test showed no correlations at the =.05 level, (Table 3).

A grouped one-tail t-test of the actual values of outbreak duration, (rather than paired samples of average values), over all twenty stands sampled showed that the duration of outbreak associated

TABLE 3: RESULTS OF LINEAR CORRELATIONS OF WSBW OUTBREAK AND FIRE OCCURENCE VARIABLES

VARIABLES	R	CASES	SIGNIFICANCE
FREQUENCY pre-1910 (Transformed) with MFI pre-1910	.110	20	-
FREQUENCY post-1910 (Transformed) with MFI post-1910	.042	20	-
DURATION pre-1910 (Ave.) with MFI pre-1910	-.125	20	-
DURATION post-1910 (Ave.) with MFI post-1910	.140	20	-
SEVERITY pre-1910 (Ave.) with MFI pre-1910	.128	20	-
SEVERITY post-1910 (Ave.) with MFI post-1910	.055	20	-
WEIGHTED FREQUENCY (by decade) with FIRE FREQUENCY (by decade)	.476	17	*

*Significant at α =.05 level.

with the fire suppression time period is significantly longer than that of the pre-fire suppression period (Table 4).

Outbreak Severity

The severity of outbreaks in each stand, represented by the severity index, ranged from .23 to .76. The average index values calculated by stand and time period ranged from zero, representing time periods with no budworm activity, to .75. A paired t-test indicated no significant increase in average severity in the fire suppression time period (Table 2). Simple linear correlation coefficients between average severity by stand and stand MFI were calculated for each time period and a one sample two-tailed z test showed no correlations at the =.05 level (Table 3). A grouped one-tailed t-test of the actual values of outbreak severity index over the twenty stands sampled showed that the severity of outbreak associated with the fire suppression time period is significantly greater than that of the pre-fire suppression period (Table 4).

Weighted Frequency

A grouped one-tailed t-test showed that the values of weighted frequency by decade in the fire suppression time period were significantly higher than those in the pre-fire suppression period (Table 4). The weighted frequency was also shown to be negatively correlated with the number of fires in all stands during the same decade ($r=-.47$, $p<0.05$).

TABLE 4: RESULTS OF GROUPED T-TESTS OF WSBW ACTIVITY VARIABLES

Variable	Cases		Mean		Standard Error		T	
	Pre-1910	Post-1910	Pre-1910	Post-1910	Pre-1910	Post-1910	Value	Significance
Outbreak Duration	16	11	13.3	25.4	1.7	4.7	-2.4 (S)	*
Outbreak Severity	16	11	.48	.66	.04	.04	-3.1 (P)	*
Weighted Frequency	10	7	20.6	38.6	6.6	7.0	-1.8 (P)	*

*Significant at = .05 level
(S) = Separate variance estimate
(P) = Pooled variance estimate

Stand Histories

The stand vegetation histories taken at every fourth study area generally showed an increase in numbers of Douglas-fir relative to ponderosa pine. Much of the invasion of Douglas-fir is represented in the stands in the lower tiers of vegetation. These stand histories are shown in Figures 5-9 .

Insect damage records maintained since 1962 indicated that no Douglas-fir tussock moth nor any other defoliating species have occurred on or in the vicinity of any of the twenty stands sampled. Although the long term effects of insecticide treatments are not fully understood, insecticide spray records were examined to determine if any of the stands sampled had been sprayed. These records were not available for individual drainages. Table 5 shows the year, national forest, number of acres treated, and the insecticide used in each treatment. Also indicated are the stands sampled in the forest that may have been involved in the treatment.

DISCUSSION

This study indicates that western spruce budworm feeding activity and the length of mean fire intervals have increased in western Montana in the past seventy-five years. A paired t-test of stand mean fire intervals indicated a significant increase in MFIs in the fire suppression time period (1911-1983). Grouped t-tests on the actual

FIG. 5: VEGETATION HISTORY PLOT
STAND 4; HORNER

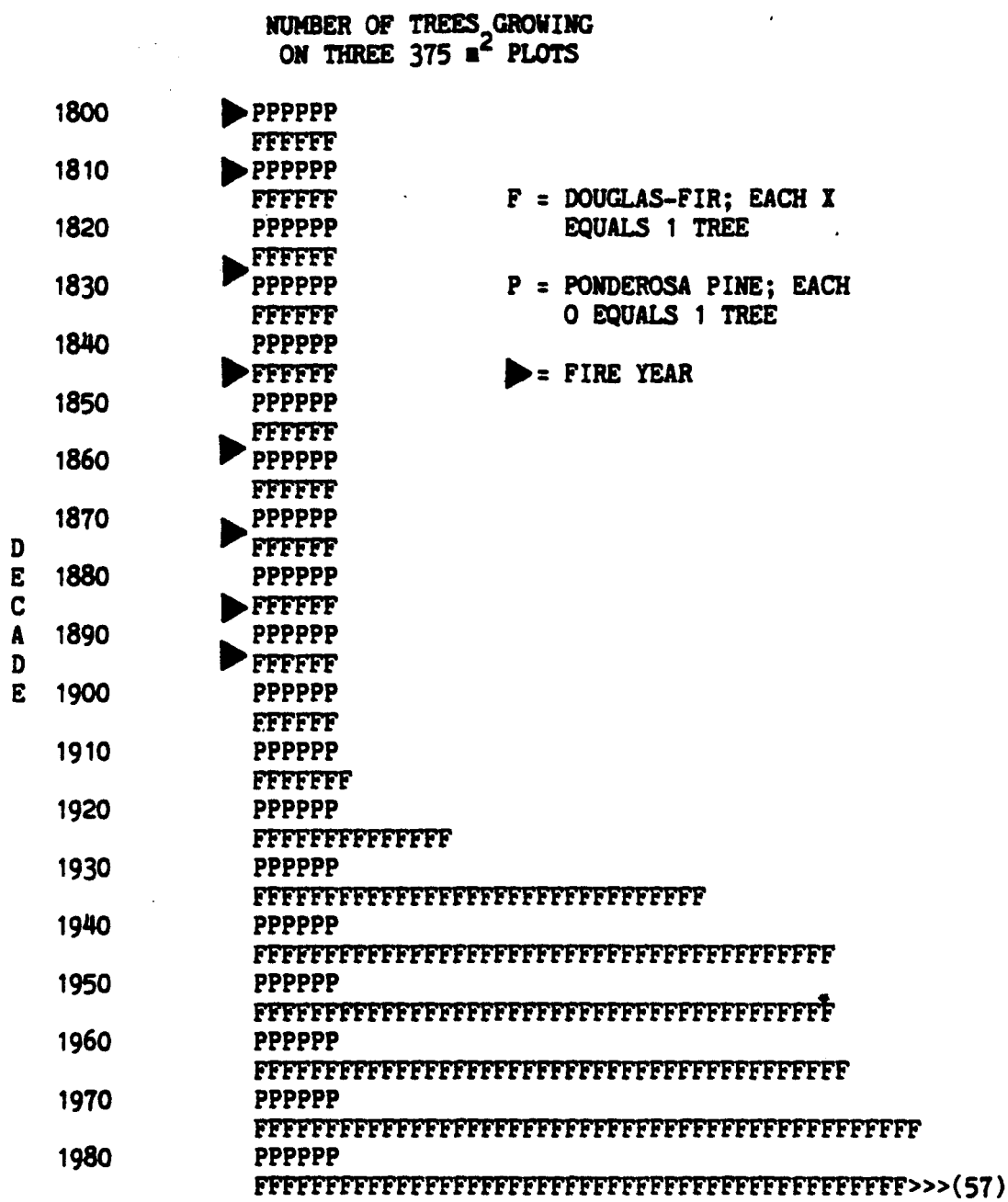


FIG. 6: VEGETATION HISTORY PLOT
STAND 8; RAILROAD CR.

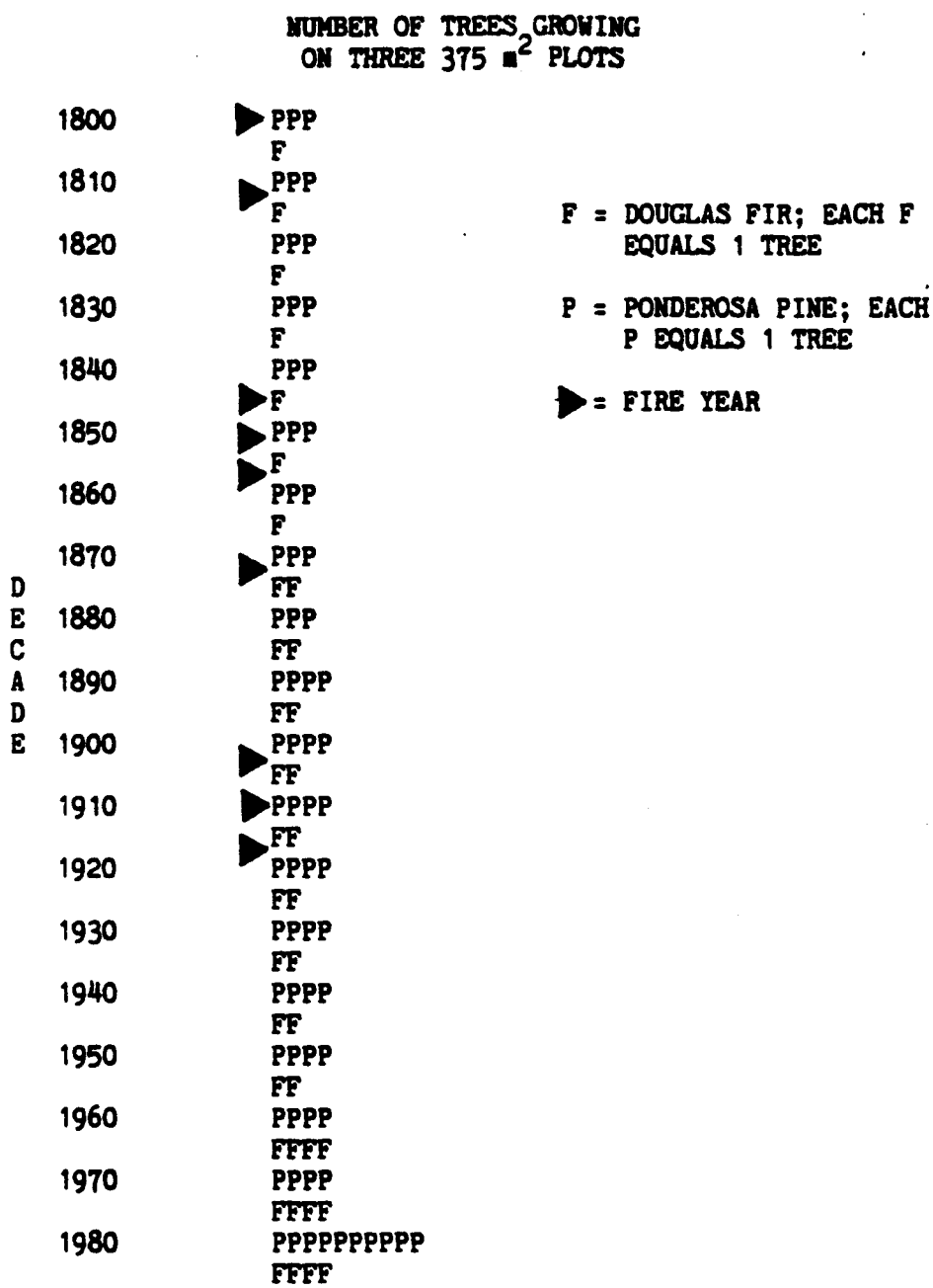


FIG. 7: VEGETATION HISTORY PLOT
STAND 12; HOG TROUGH CR.

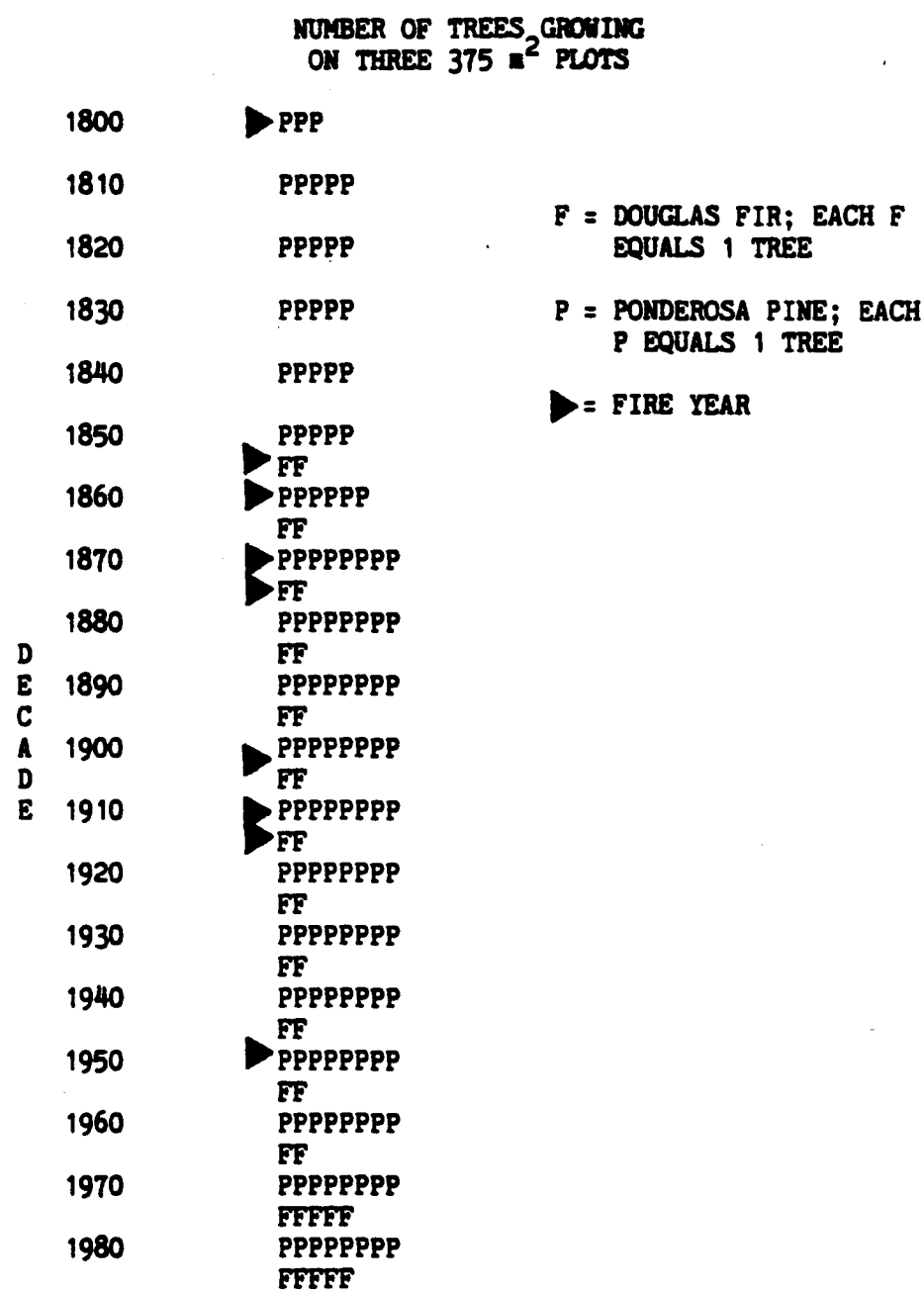


FIG 8: VEGETATION HISTORY PLOT
STAND 16; HUGHES CR.

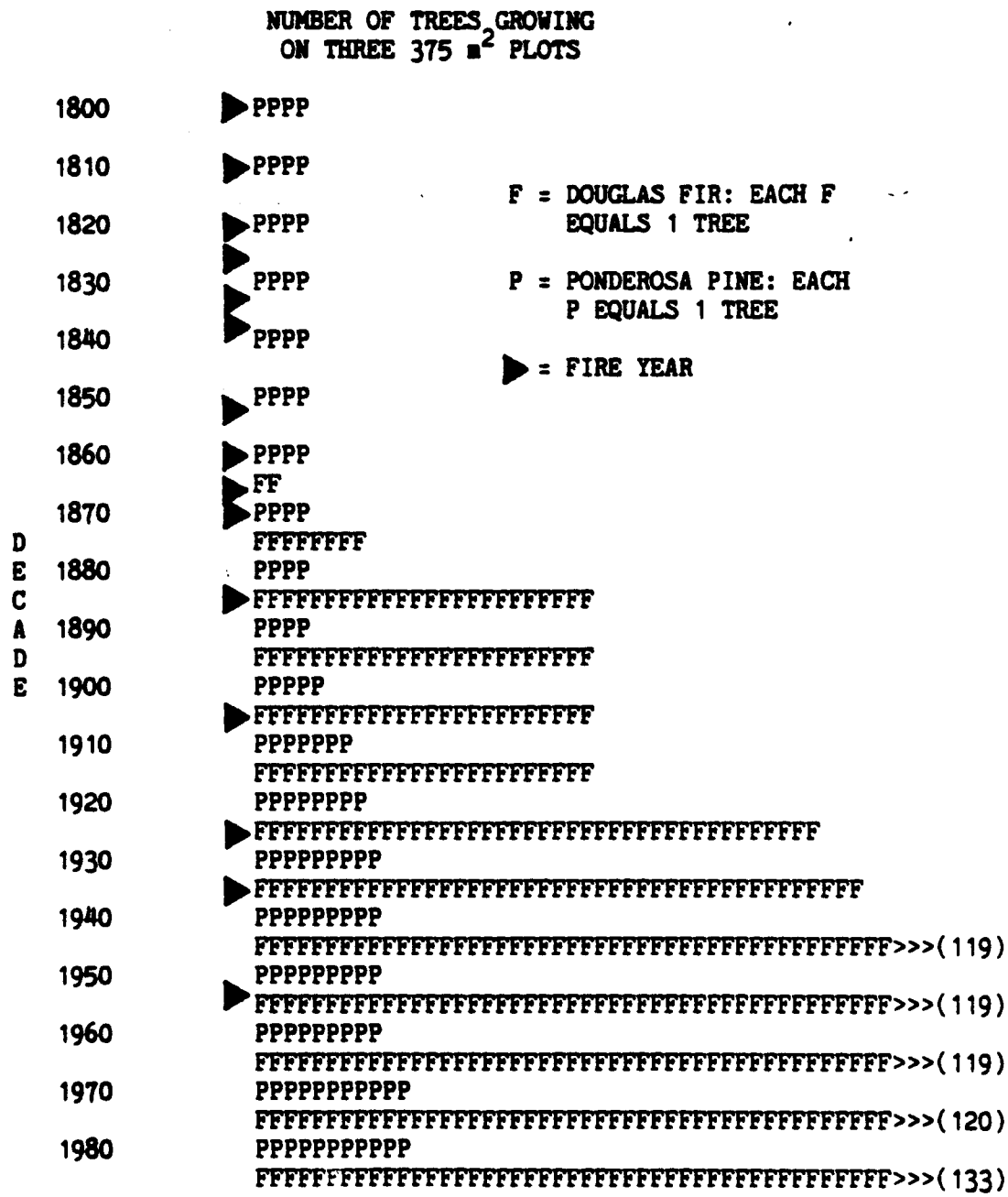
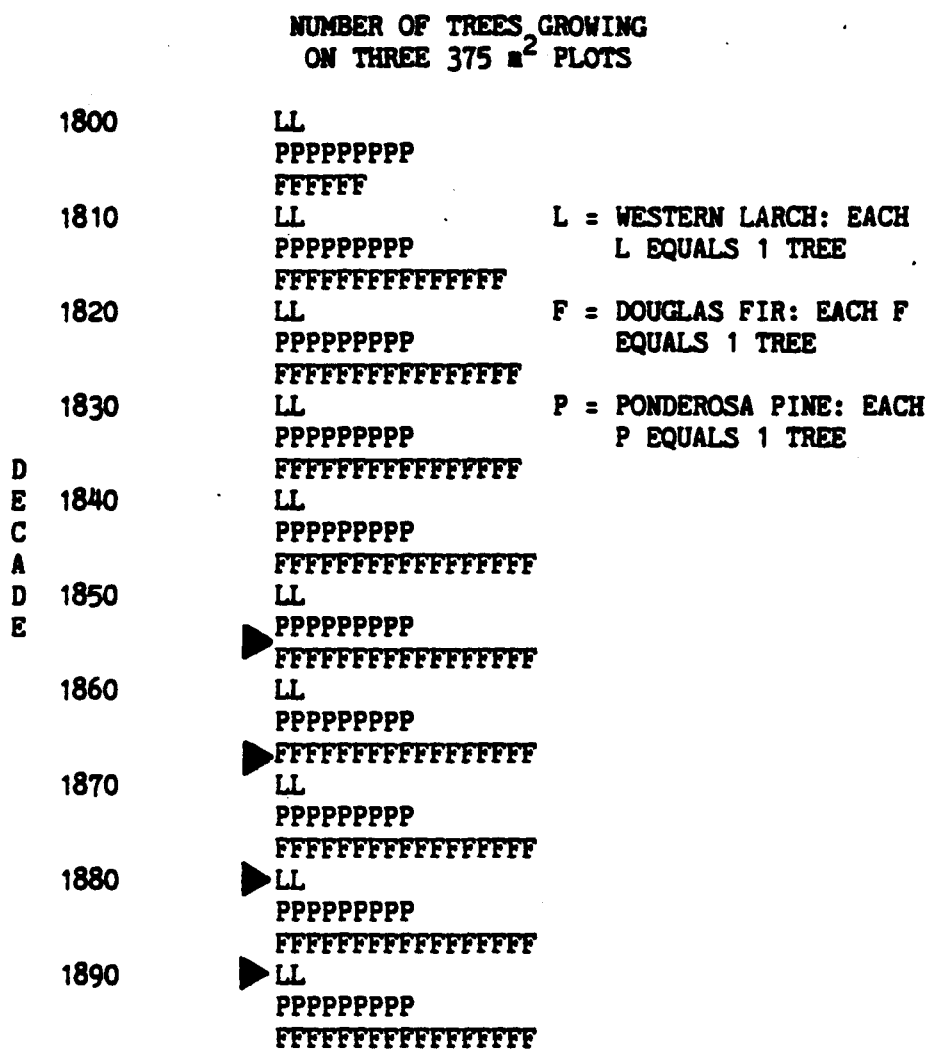


FIG 9: VEGETATION HISTORY PLOT
STAND 20 RAINY CR.



(CONTINUED ON NEXT PAGE)

FIG. 9 (CONTINUED)

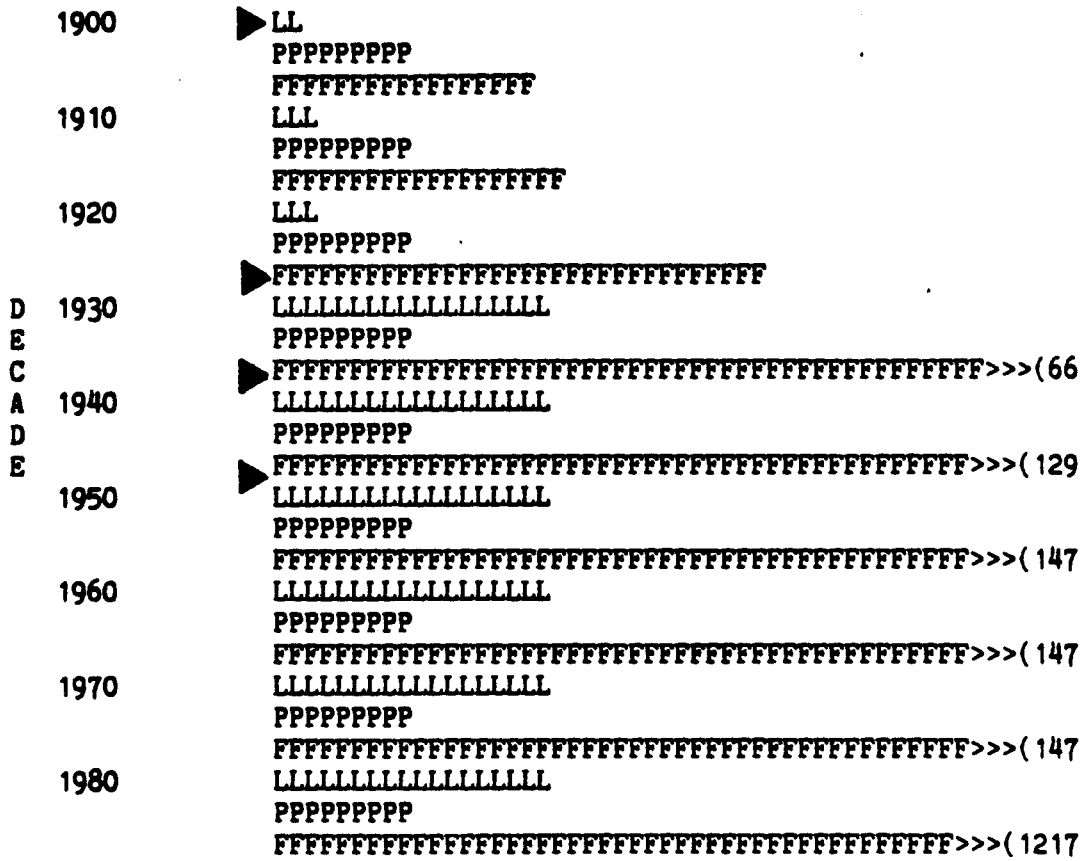


TABLE 5: INSECTICIDE TREATMENTS FOR WSBW

YEAR	NATIONAL FOREST	TYPE OF TREATMENT*	INSECTICIDE USED	ACRES TREATED	STANDS SAMPLED IN FOREST
1952	BITTERROOT	E	DDT	12,000	7-17
1955	BITTERROOT	O	DDT	169,090	7-17
1959	BITTERROOT	O	DDT	126,880	7-17
1963	BITTERROOT	O	DDT	110,190	7-17
		E	MALATHION	40	
		E	MALATHION	13,510	
	LOLO	O	DDT	64,400	1-6
		E	PHOSPHAMIDON	5,000	
1964	LOLO	E	MALATHION	160	1-6
	LOLO (AND DEERLODGE)	E	MALATHION	131,410	1-6
1965	BITTERROOT	E	MEXACARBATE	1,080	7-17
		E	NALED	1,160	
1966	BITTERROOT	E	MEXACARBATE	5,360	7-17
1968	LOLO (AND BLM, ACM)	E	MEXACARBATE	6,080	1-6
1972	LOLO	E	MEXACARBATE	500	1-6

*TYPE OF TREATMENT: E = EXPERIMENTAL; O = OPERATIONAL
**No spray treatments for WSBW have been recorded for Kootenai National

SOURCES: Johnson and Denton, 1975; pers. comm 2/85 with Bitterroot National Forest, Hamilton, Montana; Lolo National Forest, Missoula, Montana; Kootenai National Forest, Libby, Montana; and Regional Office, Northern Region, US Forest Service, Missoula, Montana.

values of outbreak duration and severity over the entire study area, and on weighted frequency by decade showed significant increases in the fire suppression time period. Weighted frequency of WSBW activity and fire frequency by decade were shown to be significantly correlated, suggesting that fire suppression has resulted in changes that are favorable to the budworm. Presumably changes in forest structure and composition such as the increase in shade tolerant, host tree species were partly responsible for the changes. Differences in WSBW activity were not apparent for outbreak frequency, or for average duration and average severity when compared by stand with paired t-tests.

Major sources of variation in MFIs between stands prior to 1910, include the burning practices of the Indians and the variability in occurrence and spread of lightning fires between study areas. Indian fires appear to have been a prominent factor for at least 500 to 1000 years prior to European settlement (Arno 1985). MFI's of stands located near zones of heavy use by Indians appear to be significantly shorter than those of similar stands in areas receiving less use by Indians (Barrett, 1981). Ignitions by European-Americans during the late 1800's may also have affected MFIs in some stands although this was not shown to be a factor increasing fire frequency by Barrett (1981). The variation caused by ignitions by Indians could not be controlled in this study, as fire history did not extend prior to the time of Indian habitation. However, the effect of ignitions by Indians was not defined as an independent variable because it was measured at the level at which

it occurred. The occurrence and spread of lightning fires was also not defined as an independent variable since comparisons were done on a stand by stand basis.

It is possible that there was some overestimation of budworm outbreak frequency, especially in the pre-fire suppression time period, which could have affected the outcome of the paired t-tests of budworm activity. Because of the built in bias of using growing trees over the course of their lifetime, there may be a diluting effect on the radial growth response to budworm infestation. Defoliation is greatest in small understory trees. The density of larvae in these trees can be quite high since larvae commonly fall out of the trees above. A larger proportion of the foliage of understory trees is in current-season needles, which are the first to be consumed by the budworm. In addition, these small trees are often of low vigor and have comparatively less foliage than the dominant trees, so they recover less rapidly than trees in the overstory (Johnson and Denton 1975). Since most of the trees sampled were small during part of the pre-fire suppression time period, they may have been more vulnerable to budworm defoliation than in the later time period. Smaller outbreaks may not have hindered radial growth on the large trees of the fire suppression time period as much as similar outbreaks would have on the same trees in the earlier period.

There is a small chance of attributing radial growth loss from fire scorch to budworm activity, thus overestimating the number of budworm outbreaks. Crown scorch by fire can result in a radial growth reduction of both ponderosa pine and Douglas-fir. Craighead (1927), reported the cessation of growth rings for up to five years in ponderosa pine after severe fire damage. Douglas-fir foliage is more heat sensitive than ponderosa pine and thus the Douglas-fir may experience more radial growth reduction due to fire scorch for a given intensity fire (Lotan et al. 1981). Although some of the periods of growth reduction in Douglas-fir that were labeled as outbreaks occurred immediately after a recorded fire, it is impossible to know which growth reductions were actually due to fire scorch. The six year minimum duration chosen for outbreak determination should reduce the probability of overestimating budworm activity since severe fires would likely have also affected the growth of ponderosa pine and thus precluded the labeling of the periods as outbreaks.

Growth reduction from other host specific defoliating agents may cause the number of budworm outbreaks to be overestimated. The Douglas-fir tussock moth, (Orgyia pseudotsugata), causes a pattern of growth suppression in Douglas-fir similar to that of the budworm (Johnson and Denton 1975). However, tussock moth outbreaks are evidently infrequent in Montana with the first one noted in 1963, (Tunnock 1973). Other defoliating agents specific to Douglas-fir include the black-headed budworm, (Acleris variana), the spruce

coneworm, (Dioryctria reniculella), the spruce spider mite, (Oligonychus ununguis), and needle cast fungi, (Rhabdocline pseudotsugae). However, these agents are not known to cause radial growth patterns that are similar to the growth reductions caused by WSBW, (Clint Carlson, Research Forester, USFS Intermountain Forest Sciences Laboratory, Missoula, Montana, pers. comm. 2/85). Insect damage records maintained since 1962 indicated no evidence of past outbreaks of Douglas-fir tussock moth or other host specific defoliating species in any of the stands sampled between 1962 and 1983. Prior to 1962 there is a small chance of overestimating WSBW activity by incorrectly attributing radial growth loss resulting from other factors to effects of the budworm.

Frequency of outbreak may have remained fairly constant between the two time periods, as the paired test supports, because of biotic factors, and "natural cycles". Factors other than food supply, such as long term weather patterns are thought to determine the occurence of epidemic populations (Carlson et al. 1983). Once an outbreak occurs the duration and severity may be extended, because of favorable stand conditions created by the suppression of fire. The existence of longer outbreaks may indirectly lower the frequency in the fire suppression time period, because fewer non-outbreak years are available for infestations to begin.

The results of the paired t-tests may have been affected by the study design. The sample size of twenty stands may have been too small and the time periods too short to test variables that have such large variation. The resultant standard errors would then have been too large to show differences in the means of the paired values. This may be the reason differences in outbreak duration and severity were apparent from the grouped t-tests but not from the paired t-tests.

Uncontrolled sources of variation of budworm activity include insecticide spray programs and genetic differences within host tree populations. Insecticide spray programs beginning in the early 1950's and continuing until the mid-1960's temporarily reduced WSBW populations (Johnson and Denton 1975). Long term effects of these programs on overall budworm activity are not fully understood, therefore, the effects of these treatments cannot be quantified. The insecticide spraying is thought to have had only a minor delaying effect on budworm outbreaks (Fellin et al. 1983). The year of treatment, insecticide sprayed, National Forest in which spraying took place, and sampling units located in National Forest are listed in Table 5.

Genetic differences within host tree populations can affect whether a host tree is attractive to and/or able to survive a budworm outbreak (McDonald 1979,1981). Thus, results may be conservative as those trees that did not survive or grow to become large trees could not be sampled.

The pine butterfly, (Neophasia menapia), is a defoliator of ponderosa pine and past outbreaks may have caused radial growth loss in pine, (Evendon 1940). However, since the effects of this insect are on the nonhost tree species and do not cause growth loss in Douglas-fir, it should not have affected the analysis of WSBW history.

As indicated in three of the five stand vegetation history graphs (Figs 5 to 9), the suppression of fire has evidently been responsible for the increase of Douglas-fir, a species more shade tolerant, but less fire resistant as a young tree, than ponderosa pine. Stands 4, 16, and 20 were on NE, SW, and SE slopes respectively. All three showed dramatic increases in the numbers of Douglas-fir over time, and each, as noted on the graphs, had a history of budworm. The two stands that showed no increase in the numbers of Douglas-fir, stands 8 and 12, were both on much drier, grassy, south facing slopes with scattered large ponderosa pine and Douglas-fir and little or no understory. Stand 8 had a history of budworm activity while stand 12, which was only about a mile away, had none. While only five stand histories were examined, it is noteworthy that: 1) as expected there has been a general increase of Douglas-fir, mostly in the understory, resulting in the type of stands that are reported to suffer from heavy defoliation, and 2) there are factors other than stand composition that affect budworm activity, which may or may not be affected by fire frequency. Possible factors include long term weather patterns, past budworm history in adjacent stands, and the continuity of budworm susceptible stands.

SUMMARY

To summarize:

1) Mean fire intervals for individual stands were significantly greater in the fire suppression time period than in the pre-fire suppression time period.

2) WSBW outbreak frequency, average duration and average severity were not significantly greater in the fire suppression time period than in the pre-fire suppression time period for individual stands, (=.05).

3) No significant correlations were found between the values of outbreak frequency, duration, or severity, and the values of mean fire interval for individual stands, (=.05).

4) Values for pooled data of outbreak duration, severity, and weighted frequency over the twenty stands sampled were significantly higher in the fire suppression time period, (=.05).

5) Weighted frequency of apparent budworm infest- ation by decade was significantly correlated to fire frequency by decade ($r=-0.47$, $p<.05$).

6) Three of the five stand vegetation histories showed dramatic increases in the numbers of Douglas-fir since the beginning of the fire suppression time period. Most of this increase is evident in the understories of the stands.

CONCLUDING REMARKS

This study supports the contention that WSBW is native to western Montana and was present well before the first recorded outbreaks. It also suggests that forest management techniques, including fire suppression and logging practices that encourage the development of dense, tiered stands with large host tree components will lead to longer, more severe, western spruce budworm outbreaks. Another variable that may show a change due to the suppression of fire is the areal extent of outbreaks. Fire suppression has resulted in changes in the mosaic of forest communities, allowing extensive continuous areas of forested land to develop, that are favorable for budworm attack. Without a mosaic to cause breaks in the forest type the budworm may be able to move easily through very large areas. A transect method, similar to Arno and Sneck's (1977) method of determining the size of past fires may be useful in determining the extent of past budworm outbreaks.

Management of budworm-susceptible areas should include silvicultural treatments such as prescribed fire or treatments that mimic fire's effects such as cutting and thinning to promote thrifty, species diverse stands with smaller proportions of host trees and to encourage the growth of non-host seral tree species such as ponderosa pine and lodgepole pine (Pinus contorta)(Carlson et al. 1983; Fellin et al. 1983; Williams et al. 1971; Schmidt et al. 1983).

Prescribed natural fire may be especially important in wilderness areas where budworm activity may be increasing, but other silvicultural treatments are not appropriate or allowed.

APPENDIX 1

STAND FIRE HISTORIES

X = FIRE SCAR

STAND 1; LOLO CR.	
DATE	FIRE SCARS
1980	
1970	
1960	
1950	
1940	
1930	
1920	XX
1910	
	X
1900	
1890	XXX
1880	XX
1870	
	XXX
1860	
1850	
1840	
1830	
	XXX
1820	
1810	
1800	
1790	
	XXX
1780	

TOTAL CROSS SECTIONS: 3
STAND SAMPLED BY AUTHOR

STAND 2; HOBO GULCH	
DATE	FIRE SCARS
1980	
1970	
1960	
1950	
1940	
1930	
1920	XXX
1910	
	X
1900	
1890	XX
1880	
1870	
1860	
1850	
	X
1840	
1830	
	XXX
1820	
1810	
1800	
	XX
1790	X
1780	

TOTAL CROSS SECTIONS: 5
STAND SAMPLED BY AUTHOR

X = FIRE SCAR

STAND 3: ROCK CR.		STAND 4: HORNER	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
1950		1950	
1940		1940	
1930		1930	
1920		1920	
1910		1910	
1900		1900	
			XXX
1890	XXXX	1890	
			XXX
1880	X	1880	
			XXX
1870	X	1870	
1860		1860	XXX
			XX
1850	X	1850	
1840	X	1840	
1830	XX	1830	XXX
	XX		
1820	X	1820	
1810		1810	X
	XX		
1800		1800	X
1790		1790	
	XX		
1780		1780	
TOTAL CROSS SECTIONS: 6		TOTAL CROSS SECTIONS: 3	
STAND SAMPLED BY BARRETT (1981)		STAND SAMPLED BY AUTHOR	

X = FIRE SCAR

STAND 5: GRIZZLY CR.		STAND 6: HAY CR.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	X
1950		1950	
			X
1940		1940	
1930		1930	
1920		1920	
1910		1910	XXX
	XX		
1900	X	1900	XXX
	XX		
1890		1890	
1880		1880	
1870		1870	
			XX
1860	XXX	1860	
1850		1850	XXXXX
1840		1840	
	XXX		
1830		1830	XXXX
			X
1820		1820	X
1810		1810	
	XXX		X
1800		1800	
			X
1790		1790	XXX
			X
1780		1780	
TOTAL CROSS SECTIONS: 3		TOTAL CROSS SECTIONS: 5	
STAND SAMPLED BY AUTHOR		STAND SAMPLED BY BARRETT (1981)	

X = FIRE SCAR

STAND 7: ONEHORSE CR.

DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1880	
1970		1870	
			X
1960		1860	
			XXXXX
1950		1850	XXXXXX
1940		1840	XX
	X		XXX
			XX
1930		1830	XXX
			XX
			XXXX
1920	XXXX	1820	
1910		1810	XXXXX
			XXX
1900		1800	XXXX
	XXXX		XXX
1890	XXXXXX	1790	
	XXX		X
	XXXX		XXXX
		1780	

TOTAL CROSS SECTIONS: 8
STAND SAMPLED BY ARNO (1976)

X = FIRE SCAR

STAND 8: RAILROAD CR.		STAND 9: GOAT MTN.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
70			
1950		1950	
1940		1940	X
			X
1930		1930	X
1920	X	1920	
1910	XX	1910	XXX
	XXXX		X
1900		1900	
1890		1890	X
			X
1880		1880	
	X		XX
1870		1870	XX
1860	XX	1860	XXX
			XX
1850	X	1850	
	X		XX
1840		1840	XXX
1830		1830	X
			X
1820		1820	
			XXX
1810	X	1810	X
			X
1800	X	1800	X
1790		1790	
	XX		XXX
1780		1780	X
TOTAL CROSS SECTIONS: 5		TOTAL CROSS SECTIONS: 6	
STAND SAMPLED BY BARRETT (1981)		STAND SAMPLED BY BARRETT (1981)	

X = FIRE SCAR

STAND 10: CUTOFF GU.		STAND 11: McCALLA CR.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960	XX	1960	
	X		
1950	XX	1950	
	X		
1940		1940	
	X		
1930		1930	
1920	X	1920	
1910	XX	1910	
1900		1900	
	X		
1890		1890	XX
1880	X	1880	
			XXX
1870		1870	
	X		
1860		1860	
	X		XXXX
1850		1850	X
			X
1840	XX	1840	
			XXX
1830		1830	XXX
	X		XX
1820	X	1820	XX
			XX
1810		1810	X
			XXXX
1800		1800	
			XX
1790		1790	
			XXX
1780	XXX	1780	
TOTAL CROSS SECTIONS: 5		TOTAL CROSS SECTIONS: 5	
STAND SAMPLED BY BARRETT (1981)		STAND SAMPLED BY BARRETT (1981)	

X = FIRE SCAR

STAND 12: HOG TROUGH CR.		STAND 13: INDIAN TREES	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
1950	X	1950	
1940		1940	X
			X
1930		1930	
1920		1920	
	XX		
1910	XXXX	1910	
	XXX		
1900		1900	X
			X
1890		1890	X
1880		1880	
	X		
1870	XX	1870	XX
1860	XXX	1860	
	X		X
1850		1850	XX
1840		1840	XX
			X
1830		1830	
			XX
1820		1820	XX
.pg		1810	XXX
1800		1800	
1790		1790	
	XX		XXXX
1780		1780	
TOTAL CROSS SECTIONS: 8		TOTAL CROSS SECTIONS: 4	
STAND SAMPLED BY BARRETT (1981)		STAND SAMPLED BY BARRETT (1981)	

X = FIRE SCAR

STAND 14: TOLAN CR.		STAND 15: SCHOOL PT.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
1950		1950	
1940		1940	
1930		1930	
1920		1920	
1910		1910	
1900		1900	
1890	XXX	1890	XX
1880	XX	1880	
			X
1870	X	1870	
	XXX		X
1860		1860	
1850		1850	
	XXX		
1840		1840	
1830		1830	
1820	XX	1820	
	X		
1810		1810	
	X		
1800		1800	X
	X		
1790		1790	
	XXXX		
1780		1780	
TOTAL CROSS SECTIONS: 5		TOTAL CROSS SECTIONS: 2*	
STAND SAMPLED BY ARNO (1976)		STAND SAMPLED BY ARNO (1976)	

* One additional date taken from 2 other samples.

X = FIRE SCAR

STAND 16: HUGHES CR.		STAND 17: TWO BEAR CR.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
	X		
1950		1950	
1940		1940	
1930	X	1930	
	X		
1920		1920	
1910		1910	
	X		
1900		1900	
			XXX
1890		1890	XXX
	X		
1880		1880	
1870	X	1870	XX
	X		XXX
1860	X	1860	XXX
1850	X	1850	
1840		1840	
	XXX		X
1830	X	1830	XX
	X		
1820	X	1820	
			X
1810	XXX	1810	X
			X
1800	X	1800	
1790	XX	1790	X
			XX
1780	XXX	1780	
TOTAL CROSS SECTIONS:4		TOTAL CROSS SECTIONS: 6	
STAND SAMPLED BY BARRETT (1981)		STAND SAMPLED BY BARRETT (1981)	

X = FIRE SCAR

STAND 18: DOAK CR.		STAND 19: FIVE MILE CR.	
DATE	FIRE SCARS	DATE	FIRE SCARS
1980		1980	
1970		1970	
1960		1960	
			X
1950		1950	
			XX
1940	X	1940	
1930		1930	
1920		1920	
1910		1910	
			XX
1900		1900	XXXXX
1890	XXX	1890	
			X
1880		1880	XXX
			XX
1870		1870	XXX
	X		
1860	X	1860	
			XX
1850		1850	XXXX
			X
1840	X	1840	
1830		1830	XXX
			XXX
1820		1820	
			X
1810		1810	
			XX
1800		1800	XX
	X		X
1790		1790	X
1780		1780	X

TOTAL CROSS SECTIONS: 3
STAND SAMPLED BY BARRETT (1981)

TOTAL CROSS SECTIONS: 5
STAND SAMPLED BY BARRETT (1981)

X = FIRE SCAR

STAND 20: RAINY CR.

DATE	FIRE SCARS
1980	
1970	
1960	
1950	
	X
1940	
	X
1930	X
1920	
1910	
	X
1900	X
1890	XXX
1880	X
1870	
1860	
	XX
1850	
1840	
1830	
1820	
1810	
1800	
	XX
1790	
1780	

APPENDIX 2: BUDWORM AND MFI DATA BY TIME PERIOD

STAND	NUMBER OF OUTBREAKS	FREQUENCY PFSP	FREQUENCY FSP	AVE. DURATION PFSP	AVE. DURATION FSP	AVE. SEVERITY PFSP	AVE. SEVERITY FSP	*MFI PFSP	*MFI FSP
1	0	.000	.000	0.0	0.0	.00	.00	21.8	72.0
2	0	.000	.000	0.0	0.0	.00	.00	23.2	72.0
3	4	.021	.028	10.5	21.5	.33	.75	12.4	72.0
4	2	.010	.014	6.0	14.0	.57	.67	13.8	72.0
5	1	.010	.000	25.0	0.0	.70	.00	20.0	72.0
6	1	.000	.014	0.0	16.0	.00	.69	12.3	24.0
7	2	.010	.014	17.0	26.0	.23	.56	6.6	32.0
8	1	.000	.014	0.0	66.0	.00	.72	15.9	72.0
9	3	.010	.028	11.0	17.5	.28	.71	7.5	18.3
10	2	.021	.000	11.0	0.0	.48	.00	16.0	10.3
11	2	.010	.014	11.0	26.0	.45	.64	8.9	72.0
12	0	.000	.000	0.0	0.0	.00	.00	19.5	23.7
13	2	.010	.014	7.0	32.0	.70	.76	10.5	24.5
14	3	.021	.014	23.0	21.0	.54	.63	12.5	72.0
15	1	.010	.000	8.0	0.0	.54	.00	29.0	72.0
16	1	.010	.000	9.0	0.0	.40	.00	14.3	18.7
17	0	.000	.000	0.0	0.0	.00	.00	10.3	72.0
18	1	.010	.000	10.0	0.0	.33	.00	17.5	72.0
19	0	.000	.000	0.0	0.0	.00	.00	7.9	24.0
20	1	.010	.000	8.0	0.0	.75	.00	22.0	18.3

PFSP = PRE-FIRE SUPPRESSION TIME PERIOD (1814-1910)
FSP = FIRE SUPPRESSION TIME PERIOD (1911-1983)

*PRE-FIRE SUPPRESSION TIME PERIOD FOR MFI BEGINS IN 1780

LITERATURE CITED

Arno, S.F. 1985. Ecological effects and management implications of Indian fires: IN Proceedings-Symposium and Workshop on Wilderness Fire. USDA For. Serv. Gen. Tech. Rep. INT-182. pp. 81-86.

Arno, S.F. 1980. Forest fire history in the northern Rockies. J. For. (78)8:460-465.

Arno, S.F. 1976. The historical role of fire on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-187.

Arno S.F., and T.D. Petersen. 1983. Variation in estimates of fire intervals: A closer look at fire history on the Bitterroot National Forest. USDA For. Serv. Res. Pap. INT-301.

Arno S.F., and D.G. Simmerman. 1982. Review draft of forest succession of four habitat types in western Montana. Intermt. For. and Range Exp. Stn., Northern For. Fire Lab., Missoula, Montana.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain west. USDA For. Serv. Gen. Tech. Rep. INT-42.

Bain, O. 1972. Observation on the behavior and effectiveness of three ant species (Hymenoptera:Formicidae) attacking the western spruce budworm Choristoneura occidentalis (Lepidoptera:Tortricidae) in western Montana. Master's thesis, University of Montana, Missoula, Montana.

Barrett, S.W. 1981. Relationship of Indian-caused fires to the ecology of western Montana forests. Master's thesis, University of Montana, Missoula, Montana.

Blais, J.R. 1981. Recurrence of spruce budworm outbreaks for two hundred years in western Quebec. For. Chron. 57:273-275.

Blais, J.R. 1962. Collection and analysis of radial-growth data from trees for evidence of past spruce budworm outbreaks. For. Chorn. 38:474-484.

Campbell, R.W. and T.R. Torgersen. 1982. Some effects of predaceous ants on western spruce budworm pupae in northcentral Washington. Environ. Entomol. 11:111-114.

Carlson, C.E., D.G. Fellin, and W.C. Schmidt. 1982. The western spruce budworm in northern Rocky Mountain forests: a review of

ecology, past insecticidal treatments, and silvicultural practices. Scheduled for publication IN: Proceedings of the Symposium on the Management of Second-growth Forests: The State of Knowledge and Research Needs. University of Montana, Missoula, MT.

Carlson, C.E., and W.W. McCaughey. 1982. Indexing western spruce budworm activity through radial increment analysis. USDA For. Serv. Res. Pap. INT-291.

Craighead, F.C. 1927. Abnormalities in annual rings resulting from fires. J. For. 27(7):840-842.

Davis, K.M. 1980. Fire history of a western larch/Douglas-fir forest type in northwestern Montana. IN: Proceedings of the Fire History Workshop. USDA For. Serv. Gen. Tech. Rep. RM-81. pp.69-74.

Davis, K.M., B.D. Clayton, and W.C. Fischer. 1980. Fire ecology of Lolo National Forest habitat types. USDA For. Serv. Gen. Tech. Rep. INT-79.

Dickman, A. 1978. Reduced fire frequency changes species composition of a ponderosa pine stand. J. For. 79:24-25.

Evendon, J.C. 1940. Effects of defoliation by the pine butterfly upon ponderosa pine. J. For. 38: 949-955.

Fauss, D.L. and W.R. Pierce. 1969. Stand conditions and spruce budworm damage in a western Montana forest. J. For. 67(5):322-325.

Fellin, D.G. 1980. A review of some interactions between harvesting, residue management, fire, and forest insects and diseases. Environmental Consequences of Timber Harvesting in Rocky Mountain Coniferous forests, Symposium Proceedings. USDA For. Serv. Gen. Tech. Rep. INT-90. pp. 335-414.

Fellin, D.G., and J.E. Dewey. 1982. The western spruce budworm. Insect and Disease Leaflet 53. USDA For. Serv., Wash. D.C.

Fellin, D.G., R.C. Shearer, and C.E. Carlson. 1983. Western spruce budworm in the northern Rocky Mountains. West. Wildland. 9(1):2-7.

Gruell, G.E., W.C. Schmidt, S.F. Arno, and W.J. Reich. 1982. Seventy years of vegetation change in a managed ponderosa pine forest in western Montana. USDA For. Serv. Gen. Tech. Rep. INT-130.

Hard, J., S. Tunnock, and R. Eder. 1980. Western spruce budworm defoliation trends relative to weather in the Northern region, 1969-1979. USDA For. Serv. Rep. 80-4.

Johnson, P.C. and R.E. Denton. 1975. Outbreaks of the western spruce budworm in the American northern Rocky Mountains area from 1922 through 1971. USDA For. Serv. Gen. Tech. Rep. INT-20.

Lotan, J.E. ED. 1981. Effects of fire on flora. A state-of-the-knowledge review. USDA For. Serv. Gen. Tech. Rep. WO-16.

McCune, B. 1982. Site, history, and forest dynamics in the Bitterroot canyons of Montana. Ph.D dissertation, University of Wisconsin, Madison, Wisconsin.

McDonald, G.I. 1981. Differential defoliation of neighboring Douglas-fir trees by western spruce budworm. USDA For. Serv. Res. Note INT-306.

McDonald, G.I. 1979. Resistance of Douglas-fir to western spruce budworm. Results of a preliminary progeny test. USDA For. Serv. INT-264.

Miller, C.A. 1958. The measurement of spruce budworm populations and mortality during the first and second larval instars. Can. J. Zool. 36:409-422.

Pfister, R.D., B.L. Kovalchik, S.F. Arno, and R.C. Presby. 1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34.

Romme, W.H. 1980. Fire history terminology: report of the ad hoc committee. USDA For. Serv. Gen. Tech. Rep. RM-81.

Schmidt, W.C. 1981. Forests of the Rocky Mountain West. IN: Effects of Fire on Flora-A State of Knowledge Review (Lotan and others). USDA For. Serv. Gen. Tech. Rep. WO-16, Washington, D.C. p. 11-16.

Schmidt, W.C., D.G. Fellin and C.E. Carlson. 1983. Alternatives to chemical insecticides in budworm-susceptible forests. West. Wildland. 9(1):13-19.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co. San Francisco, CA. 427-428.

Stokes, M.A. and J.H. Dieterich. ED. 1980. Proceedings of the fire

history workshop. USDA For. Serv. Gen. Tech. Rep. RM-81.

Tunnock, S. 1973. The Douglas-fir tussock moth in the Northern Region - a cartographic history of outbreaks from 1928 to 1973. USDA For. Serv. Div. of State and Private Forestry, Northern Region Rep., No. 73-27, Missoula, MT.

USDA. 1976. The western spruce budworm problem in Idaho and Montana. USDA For. Serv. R1-76-24.

Wellington, W.G. 1949. The effects of temperature and moisture upon the behavior of the spruce budworm. Sci. Agr. 29:201-215, 216-229.

Whiteside, J.M., and V.M. Carolin. 1961. Spruce budworm in the western United States. USDA For. Serv., For. Pest Leaflet 53.

Williams, C.B., P.J. Shea, and G.S. Walton. 1971. Population density of western spruce budworm as related to stand characteristics in the Bitterroot National Forest. USDA For. Serv. Res. Pap. PSW-72.

Wright, Jr., H.E. and M.L. Heinselman. 1973. The ecologic role of fire in natural conifer forests of western and northern North America. Quat. Res. 3:317-328.